# Partner Program Directive

ISS PPD 1011 Rev C

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TO: Distribution

SUBJECT: **Multilateral International Space Station (ISS) and ISS Visiting Vehicle Jettison Policy**

OFFICE OF PRIMARY RESPONSIBILITY: ISS Systems Engineering and Integration Office

## 1.0 PURPOSE

The purpose of this Partner Program Directive (PPD) is to outline the ISS Program policy on jettisoning objects from the ISS and ISS Visiting Vehicles to/from the ISS.

## 2.0 SCOPE

This policy addresses the risk acceptance rationale, analysis and acceptance process for proposed jettisons from the ISS and/or Visiting Vehicles. This policy defines a jettison candidate as any object released from the ISS or an ISS Visiting Vehicle while the vehicle is in free flight, as well as any deployables originating from those objects. This policy will also address the ISS Program level approval process, including programmatic agreements covering the work to be performed by the ISS Program associated with approval of a jettison candidate.

This policy will cover all jettison candidates to be jettisoned from the ISS or an ISS Visiting Vehicle. These items may fall into one or more of the following categories:

1. Items that pose a safety issue for the ISS or for return onboard an ISS Visiting Vehicle (contamination, materials degradation, etc.).
2. Items that negatively impact ISS utilization, return manifest or on-orbit stowage manifests.
3. Items that represent an Extravehicular Activity (EVA) timeline savings large enough to reduce the sum of the risks of EVA exposure time and the orbital environment's hazardous debris population, compared to the sum of such risks without a jettison.
4. Items that are designed for jettison.

## 3.0 DEFINITIONS

The following definitions will be used throughout this document.

| Key Word / Phrase | Definition |
|---|---|
| Jettison | The intentional, controlled release of an object from the ISS or an ISS Visiting Vehicle, usually via manual release by an extravehicular crewmember or through other methods of release (e.g., robotically). |
| Deployable | Any constituent portion of a primary payload, which can separate into its own free-flying object either intentionally or under credible failure scenarios. Examples include secondary satellite payloads, drag parachutes, tethers, harpoons, nets, probes, chip sats, etc. |
| Propulsive Candidate | Jettison candidates with systems enabling translational maneuvering capability i.e. delta-velocity (dV). These are typically defined as candidates with chemical or electrical propulsion mechanisms, though any candidate with a mechanism of performing translational maneuver could be considered propulsive. |
| TOPO | Trajectory Operations and Planning Officer for ISS |
| USSPACECOM | United States Space Command. This office manages the operation of the U.S. Space Surveillance Network. |
| 18SPCS | 18th Space Control Squadron |
| KOS | Keep Out Sphere – a 200 meter radius sphere centered about the ISS |
| CNV | Conjunction Notification Volume – a ±2 km radial by ±25 km down track by ±25 km cross track rectangular keep out zone centered about the ISS |
| Passivation | The elimination of all stored energy and minimization of the chance of post-jettison explosion or fragmentation. Reference the Inter-Agency Space Debris Coordination Committee (IADC) Space Debris Mitigation Guidelines (March 2020) for examples of passivation actions. |
| Expedited Approval Criteria | Simplified criteria, which ensure compliance with the various, jettison policy requirements when met. Expedited Approval Criteria are not required for jettison approval, but serve to expedite the analysis and approval process. |
| VIPER | Vehicle Integration, Performance, Environments, and Resources. VIPER is a team within the ISS Program Systems Engineering and Integration Office, mail code OM. |

## 4.0 POLICY

The nominal method for disposing of objects from the ISS is to transfer them to an ISS Visiting Vehicle (Progress/ H-II Transfer Vehicle (HTV)/etc.) where they are either returned to Earth or destroyed during targeted atmospheric re-entry. Jettisoning objects will only be considered provided that the criteria outlined in this policy are met.

While there are risks inherent in jettisoning objects, the ISS Program recognizes that there may be significant benefits associated with jettison in terms of operational flexibility, crew safety, utilization, scientific discovery, education, etc. A thorough assessment of the risks versus the benefits will be conducted whenever a proposal to jettison any object is made. It is the intent of the ISS Program to control the number of objects that are jettisoned in order to protect against collision with ISS and ISS Visiting Vehicles, to preserve the orbital environment for world space activities, to assure ground safety from objects surviving atmospheric re-entry, and to comply with the United Nations Committee On the Peaceful Uses of Outer Space (UNCOPUOS) Space Debris Mitigation Guidelines (June 2007) and IADC Space Debris Mitigation Guidelines (March 2020).

The following sections contain criteria intended to quantify and control the additional orbital debris risk from any jettison candidate, the risk of collision a jettison candidate poses to the ISS, and the risk any jettison candidate poses to ISS Visiting Vehicles. In some sections, "Expedited Approval Criteria" are included to simplify and expedite the analysis and approval process for candidates that pose a low risk to the ISS and ISS Visiting Vehicles. Candidates that verify compliance with the "Expedited Approval Criteria" of a section are considered to meet all requirements in that section without detailed analysis. Compliance with all criteria is verified by analysis performed by the teams outlined in Section 5.

For simplicity, the following criteria are divided into two sections in this document: Section 4.1 contains criteria that all jettison candidates must meet. Section 4.2 contains criteria specific to propulsive jettison candidates.

### 4.1 Jettison Candidate Criteria

The following criteria apply to all jettison candidates, both inert and propulsive.

***Requirement 4.1-1: Trackability***

*a.* The jettison candidate(s) shall be trackable by the Space Surveillance Network (SSN). ***Verification:*** *Jettison candidates must either conform to the dimensions detailed in the Expedited Approval Criteria or be confirmed trackable by Trajectory Operations and Planning Officer (TOPO) in consultation with United States Space Command (USSPACECOM).*

**Expedited Approval Criteria**: Objects with a cross sectional area on each of three orthogonal sides greater than that of a sphere with a diameter 10 cm (78.5 $cm^2$) are considered trackable by the SSN and will meet Requirement 4.1-1.

It is important to the safety of the ISS and other orbiting assets that the number of untrackable objects in orbit be limited whenever possible. Requiring trackability for each jettison candidate ensures conjunction notifications will be available to the ISS and other orbiting assets, providing the opportunity for assets capable of performing avoidance maneuvers to prevent on-orbit collisions. Any object in Earth orbit lacking the ability to mitigate risk from an on-orbit conjunction poses a threat of generating more orbital debris.

Another source of orbital debris comes in the form of fragmentation of objects already on-orbit. The following requirements control the fragmentation risk posed by any stored energy systems on each jettison candidate.

***Requirement 4.1-2: Limit Generation of Orbital Debris***
Jettison candidates shall verify risk of on-orbit fragmentation has been controlled as follows:

a. Candidates with stored energy systems (such as batteries, pressurized volumes, propellant systems, etc.) shall be passivated by End of Mission (EOM) to the extent necessary to prevent fragmentation or generation of additional orbital debris. In cases where propellant is available at EOM, propellant depletion burns should be performed to reduce the orbital lifetime of the candidate to the maximum extent possible while still meeting the ISS re-contact requirements in Section 4.2.3.
***Verification:*** *Payload developers shall provide an EOM passivation plan to NASA explaining planned methods of fragmentation/orbital debris generation risk mitigation for the post-mission orbital lifetime.*

b. If the jettison candidate cannot or will not be passivated, design analysis shall demonstrate to the ISS Program that the risk of fragmentation over the estimated remaining orbital decay of the object, from causes other than atmospheric re-entry, is acceptable when compared with all other options.
***Verification****: Refer to NASA-STD-8719.14 for verification analysis details. The internal NASA standard for accepting no further mitigation of fragmentation risks is a maximum 1/1,000 chance of fragmentation over the remaining life.*

c. For EVA based jettisons, the sponsoring partner should suggest an existing means or provide a new means to bundle multiple jettison candidates from a single EVA into a single collected object.

**Expedited Approval Criteria:** CubeSats that are 3U in size or smaller with orbital lifetimes less than 25 years are considered to meet this requirement per guidance received from NASA's Orbital Debris Program Office (ODPO).

The following requirements are designed to limit and control the short and long-term risk of collision each jettison candidate poses to the ISS. It is the intent of the ISS Program to limit the necessity for avoidance maneuvers due to the potential negative impacts to ISS Visiting Vehicle planning, schedule, and propellant reserves.

***Requirement 4.1-3: ISS Structural Clearance***
All objects planned for jettison shall verify that they do not contact any ISS structure during jettison. Acceptable clearance from ISS structure is verified as follows:

a. For candidates to be jettisoned from the ISS via EVA, analysis shall verify that the planned velocity vector of the jettison candidate is the axis of an unobstructed cone of a 30° half-angle (minimum), and that the object is within acceptable EVA control (i.e., "handle-able") as characterized by the responsible EVA Office defined in Section 5.2 of this policy.
***Verification:*** *Coordination with the EVA office to confirm the planned jettison location and direction. The 30° half-angle clearance can be verified via MAGIK analysis, or a comparable visualization and modelling software.*

b. For candidates to be jettisoned from the ISS via robotic jettison mechanism, robotics analysis shall verify that the planned velocity vector of the jettison candidate is the axis of an unobstructed cone with half-angle greater than the worst case half-angle of accuracy of the jettison mechanism, as defined by the robotics deploy mechanism system owner and implementing ISS robotics team and verified by the ISS Safety Review Panel (ISRP).
***Verification****: Robotics analysis of the jettison location and direction which identifies the available jettison clearance cone (distance from jettison vector to ISS structure) as well as the worst-case half-angle accuracy of the jettison mechanism.*

**Expedited Approval Criteria:** A jettison from ISS, which meets all of the following criteria, is considered to meet Requirement 4.1-3:

1. The jettison is planned to occur from a location and in a direction, which has been previously approved for a prior jettison.
2. The jettison operation utilizes a previously analyzed and approved robotic jettison mechanism and jettison speed.
3. The jettison candidate's mass and dimensions fall within previously analyzed parameters for the proposed jettison mechanism.
4. There are no changes in ISS configuration, which would alter the results of the previously approved ISS clearance analysis.

ISS structural clearance requirements ensure that the jettison operation is adequately assessed to ensure no ISS structure is at risk during the act of jettison. Following immediate departure of the jettison candidate from the ISS, relative motion resulting from differential drag effects will be assessed to ensure that each candidate does not pose a risk of collision with the ISS.

***Requirement 4.1-4: Limit Risk of Re-Contact with the ISS***

All objects planned for jettison shall verify safe relative motion with the ISS as follows:

a. The jettison candidate shall clear the ISS Keep Out Sphere (KOS) within 1 orbit, and maintain a positive departing rate while in the KOS.
b. The ISS Program considers a jettison candidate's long term re-contact risk with the ISS acceptable if the candidate is shown to meet the following:
   1. In the nominal jettison scenario, as defined by the payload developer and verified by the ISRP/Vehicle Integration, Performance, Environments, and Resources (VIPER) and TOPO, the jettisoned object's return time to the ISS Conjunction Notification Volume (CNV) shall be no less than 30 days from the jettison date. ISS reboosts or avoidance maneuvers will not be considered in this analysis. *Rationale: Nominal ISS reboosts occur approximately every 30 days. Requiring greater than 30 days prior to any re-contact risk significantly increases the likelihood that a nominally planned ISS reboost maneuver will have occurred between jettison and the object's predicted return to the ISS CNV.*
   2. In the worst case contingency jettison scenario, as defined by the payload developer and verified by the ISRP/VIPER/TOPO, the jettisoned object's return

time to the ISS CNV shall be no less than 10 days from the jettison date. ISS reboosts or avoidance maneuvers will not be considered in this analysis.
*Rationale: Ten days provides sufficient time to develop object tracking, perform relative trajectory monitoring and plan an avoidance maneuver to mitigate a low speed conjunction of the jettison candidate(s) with the ISS.*

***Verification:*** *Compliance with each of the criteria in Requirement 4.1-4 will be verified by TOPO relative motion analysis or comparable Payload Developer relative motion analysis. Relative motion analysis will assume 0.05 m/s for EVA jettison unless specific realistic dV assumptions are provided by the EVA team. The dV assumed for robotic jettisons will be based on individual system capability, and agreed to by the ISRP, robotic jettison mechanism system owner, and implementing robotics team.*

**Expedited Approval Criteria:** Candidates with pre-activation and operational Ballistic Numbers (BNs) which meet the criteria in the following table are considered to have met the previous requirements in Section 4.1-4.

| Jettison $\Delta V$ (m/s) | BN (kg/m$^2$) |
|---|---|
| $0.0 \leq \Delta V < 0.5$ | 105 |
| $0.5 \leq \Delta V < 1.0$ | 115 |
| $1.0 \leq \Delta V < 1.5$ | 125 |
| $1.5 \leq \Delta V < 2.0$ | 135 |
| $2.0 \leq \Delta V$ | 150 |

BN for this criteria will be calculated using an area equal to the average of all orthogonal frontal areas of the candidate. The pre-activation configuration is defined by the candidate’s physical configuration while stowed in or attached to a robotic payload jettison system or immediately prior to EVA performed jettison. The BN of candidates to be jettisoned from ISS Visiting Vehicles will be considered on a case-by-case basis.

Jettison from ISS Visiting Vehicles will be constrained such that a Probability of Collision (Pc) with ISS can be calculated by TOPO prior to Time of Closest Approach (TCA).

***Requirement 4.1-5: Limit Risk of Conjunction with ISS from Visiting Vehicle Jettison Candidates***

All objects planned for jettison from ISS Visiting Vehicles or their associated launch vehicles shall verify that they meet the following conditions:

a. Candidates jettisoned from ISS Visiting Vehicles to an orbit lower than ISS shall be jettisoned into an orbit with a post jettison invariant apogee of at least 5 km below ISS invariant perigee during the planned jettison timeframe.

b. Candidates jettisoned from ISS Visiting Vehicles to an orbit higher than ISS shall be jettisoned from an orbit coelliptic with the ISS with a post-jettison Semi-Major Axis (SMA) of at least 45 km above the ISS SMA.

***Verification:*** *ISS Visiting Vehicle post-departure altitude profile and jettison plan will verify compliance with these altitude requirements.*

### 4.2 Propulsive Jettison Candidate Criteria

Many jettison candidates are satellite payloads with translational maneuvering capability, which can increase risk of conjunction with the ISS if left uncontrolled. The following requirements apply to all such jettison candidates, whether jettisoned from ISS or from an ISS Visiting Vehicle while in free flight.

It is necessary to establish the proper flow of trajectory data between USSPACECOM, NASA, and the propulsive candidate's mission operations team. This data flow ensures that TOPO can guarantee ISS and ISS Visiting Vehicle safety throughout the duration of a propulsive jettison candidate's lifetime.

***Requirement 4.2-1: Data Sharing***

a. The mission operations team for propulsive jettison candidates shall have a Space Situational Awareness (SSA) Sharing Agreement in place with 18SPCS. Additionally, the mission operations team must provide owner/operator generated ephemerides to 18SPCS for space catalog maintenance when an orbit-adjusting event is planned.
   ***Verification****: Payload developers will provide to NASA proof of an SSA Sharing agreement with USSPACECOM. Details on registering satellites can be found at space-track.org.*

b. The mission operations team for propulsive jettison candidates shall sign an agreement with NASA that documents a data exchange process between the TOPO office and the satellite mission operations team to maintain ISS safety.
   ***Verification:*** *Documentation (such as Payload Integration Agreements (PIA), Operations Interface Procedures (OIP), Operations Agreements (OA), etc.) will be signed by the satellite missions operations team and NASA with the necessary data exchange details, including notifications, expectations, results for on-orbit tests and translational maneuvers, trajectory data, and points of contact.*

For propulsive jettison candidates, it is necessary to establish criteria that certifies the candidate and operations team as Responsible and Safe Space Operators. In doing so, the candidate's operators will be authorized to assess safety with respect to their own vehicle, ISS, and all other objects in space. Candidates that do not meet Responsible and Safe Space Operators (RSSO) criteria will be reliant on TOPO relative motion analysis to assess ISS re-contact risk and provide a Go/No-Go decision to ensure the safety of the ISS and ISS Visiting Vehicles from the worst-case effect of a propulsive jettison candidate's actions.

***Requirement 4.2-2: Responsible and Safe Space Operator***

Operators of propulsive satellites should demonstrate that they are Responsible and Safe Space Operators while on orbit. In the event that the satellite loses the ability to successfully demonstrate any of these criteria at any point in the satellite's lifetime, the satellite's mission operations team shall notify NASA TOPO immediately. The decision on whether to continue to treat the satellite and operator as responsible and safe will be made jointly. The criteria to be considered a Responsible and Safe Space Operator are:

a. The jettison candidate successfully demonstrates that it can maneuver to a commanded attitude within an acceptable margin of error based on system limitations.
b. The jettison candidate successfully demonstrates that it can hold a commanded attitude within an acceptable margin of error based on system limitations through the duration of a translational maneuver.
c. The jettison candidate successfully demonstrates that it can achieve a commanded delta-velocity within an acceptable margin of error based on system limitations.
d. The mission operations team for the jettison candidate successfully demonstrates that they can output state vectors that compare reasonably to an independent source (ex. Tracked orbit determination solution from 18SPCS).
e. The mission operations team for the jettison candidate successfully demonstrates that they can output predicted post-burn state vectors that, when compared to actual burn performance, are sufficiently accurate for collision avoidance analysis.
f. The mission operations team for the jettison candidate has an approved Collision Avoidance process in place, which should include:
    1. Documented compliance with Requirement 4.2-1 Data Sharing above.
    2. Daily notification criteria.
       *Note: This includes receiving notifications for predicted conjunctions within a specified volume and time at least once a day.*
    3. Debris Avoidance Maneuver (DAM) criteria.
       *Note: This includes establishing a plan to mitigate the risk of collision via DAM when a predicted conjunction is within a specified volume/probability of collision at a certain time.*
    4. Translational maneuver Go/No-Go criteria based on conjunctions on the predicted post-burn trajectory.
        i. The timing of these criteria should be based on the minimum time required to perform any necessary DAM along with the amount of time needed to obtain orbit determination on the asset following a translational maneuver.
        ii. The risk to collision should be assessed with the candidate’s burn uncertainty in mind.

       *Note: This includes establishing a decision point some time before executing a translational maneuver that will involve weighing the risk of any known potential conjunctions on the predicted post-burn state. For predicted conjunctions that violate a specified volume/probability of collision and time, the maneuver will not be performed.*
g. The jettison candidate secures commands that result in translational maneuvers (i.e. data encryption, preamble).

***Verification:*** *During the Safety Review process, the propulsive candidate must provide a plan to demonstrate the Responsible and Safe Space Operator criteria on orbit. Following the first on orbit maneuver, satellite operators will provide NASA TOPO with proof that the satellite has met the aforementioned criteria to be considered a Responsible and Safe Space Operator.*

The following requirements are dependent on the propulsive candidate’s status as a Responsible and Safe Space Operator.

***Requirement 4.2-3: Limit Risk of Re-Contact with the ISS***

Propulsive candidates shall operate such that they do not impact ISS operations.

a. If a propulsive jettison candidate has not met the criteria in Section 4.2-2 to be considered a Responsible and Safe Space Operator, or the satellite loses the ability to meet those criteria, prior to planning any on-orbit maneuvers the satellite’s missions operations team shall verify that they do not pose a collision hazard to the ISS or ISS Visiting Vehicles.
    1. While operating below ISS altitude, the jettison candidate shall not modify its orbit when there exists a possibility for ISS Visiting Vehicle interference.
    2. Propulsive candidates shall verify that within credible systems failure scenarios as defined by the payload developer and ISRP, the candidate cannot maneuver itself into the ISS CNV within 10 days of failure occurrence.
       *Note: It is the responsibility of the payload developer to verify sufficient fault tolerance in the aforementioned systems to the ISRP in accordance with their respective requirements documented in SSP 30599, Safety Review Process.*
    3. While the propulsive jettison candidate is within, or has the ability to enter, the average ISS altitude range (bounded by perigee and apogee), TOPO analysis and input shall be required for a Go/No-Go prior to orbit modifying events to control hazards identified above.

b. If a propulsive jettison candidate has met the criteria in Section 4.2-2 to be considered a Responsible and Safe Space Operator, the following applies:
    1. The jettison candidate shall not enter the ISS CNV within 5 days of a planned burn.
       *Note: The jettison candidate can control its own collision hazards with respect to ISS and ISS Visiting Vehicles once deemed a responsible and safe space operator.*

## 5.0 PROCESSES

A series of analyses will be performed and reviewed prior to making the decision whether or not to jettison a candidate. The NASA VIPER Team will be responsible for managing these analyses and presenting an integrated recommendation to the ISS Program with details on the candidate and whether it meets the requirements in Section 4. The approval process includes concurrence of the Multilateral Systems Engineering and Integration Control Board (MSEICB) and the Space Station Control Board (SSCB) or ISS Mission Management Team (IMMT) forum. Additionally, all jettison candidates must be approved through the ISRP approval process documented in SSP 30599 and SSP 51721, *ISS Safety Requirements Document*. The following sections define the jettison candidate approval and analysis process.

## 5.1 Jettison Candidate Approval Process

Jettison candidates, which are identified early enough, will be included in the Increment Definition Requirements Document (IDRD) for the increment during which the object would be jettisoned, and proper notification will be provided to all affected partners. The nominal jettison analysis and approval process requires 7 months, thus delivery of jettison data to the VIPER and ISRP teams is recommended at least 7 months prior to the planned launch of the jettison candidate. Data provided later than this may delay the proposed jettison schedule. The list of data required to perform a thorough jettison assessment includes (but is not limited to):

- Mass properties of the object(s) to be jettisoned.
    - Breakdown of the stored energy systems present in the candidate, such as propellant systems, batteries, pressure vessels, etc.
- Detailed dimensions of the object(s) to be jettisoned.
- Material composition of each component of the jettison candidate.
- Proposed jettison method.
    - Proposed jettison location and orientation.
- Details of any attitude control or propulsive systems present on the candidate.
    - Details on any planned attitudes the candidate will hold during operations.
    - Propulsive system (if present) thruster capability, total system dV, planned maneuver operations, etc.
- Details on any deployables.
- Planned Operations Concept post jettison.
    - Orbital parameters and timeframe for operation.
    - Expectation duration of satellite operations and end of mission disposal strategy.
    - Testing period to demonstrate Responsible and Safe Space Operator criteria.

Once a jettison candidate has been identified, VIPER will perform a preliminary jettison assessment to determine viability of the jettison candidate and whether to pursue a formal jettison assessment. Following a formal jettison assessment and subsequent completion of the jettison candidate analysis process, VIPER will provide a recommendation to the MSEICB on whether to proceed with jettison and what constraints may be necessary for the jettison operation. The formal jettison assessment will also include review by the ISRP.

If a jettison candidate meets all criteria outlined in Section 4 and the recommendation to jettison is approved at the MSEICB, the candidate will be considered approved for jettison, pending the completion of the ISRP process, and can begin real-time jettison planning. If a jettison candidate does not meet the criteria outlined in Section 4, but sufficient rationale exists to pursue jettison, SSCB approval will be required for final approval to jettison. ISS Program approval to jettison a candidate is documented on the ISS Jettison Authorization Form (ISS_CM_048) and the approved version is available in Electronic Document Management System (EDMS). The Jettison Approval Process Flow is located in Appendix A of this policy.

For jettison requests that are made too late to be included in the IDRD, a standard Mission Control Center (MCC) chit will be initiated by the ISS Management Center (IMC). The chit shall include mass properties data sufficient to allow determination of BNs and other parameters that influence relative motion between the ISS and the candidate, ISS Visiting Vehicle trajectory planning, atmospheric entry, etc. The decision to jettison will then be made as part of the standard IMMT process. In either case, the decision will include a thorough consideration of the risks versus the gains to be achieved from jettisoning.

### 5.2 Jettison Candidate Analysis Process

Jettison analysis will be considered as standard internal work of the ISS Program technical teams as assigned by this policy. In order to conduct the required analyses, the responsible organizations must be provided adequate data on object mass properties, configuration, material composition of each component of the jettison candidate, etc. It will be the responsibility of the owner of the jettison candidate / payload developer to supply this information in a timely manner to the NASA Systems Engineering and Integration Office/OM, who will be responsible for providing these inputs to the responsible analysis organizations.

The following sections define the teams responsible for various analyses necessary to verify compliance with this policy.

***Orbital Debris***

The owner of the jettison candidate will be responsible for demonstrating that on-orbit fragmentation risk has been controlled. This includes an assessment of the possible sources of on-orbit fragmentation (pressure vessels, large batteries, etc.) and a passivation plan where necessary. Refer to requirement 4.1-2 for steps to minimize fragmentation potential. This assessment is to be provided to VIPER and the ISRP as part of the jettison candidate data delivery. For US based payloads or jettison of ISS hardware, VIPER also reviews atmospheric re-entry characteristics of jettison candidates to determine likelihood of ground casualty, either via a review of the data provided in an Orbital Debris Assessment Report (ODAR) or as a separate analysis process in coordination with ODPO. For further details on NASA technical standards to limit orbital debris, refer to NASA-STD-8719.14.

***Relative Motion Analysis***

The NASA ISS Trajectory Branch/CM4 will be responsible for conducting the relative motion analyses for all jettison candidates during US Segment (USOS) based EVAs or using US, Canadian, European, or Japanese robotic or vehicular assets. RSC-E ballistics experts will conduct analyses for all jettison candidates during Russian Segment (RS) based EVAs or using Russian robotic or vehicular assets. In all cases, the responsible organization will coordinate with their technical counterparts within the other partners, especially those with ISS Visiting Vehicles operating in the ISS orbit plane during the lifetime of the proposed jettison. These analyses will include an assessment of the relative motion between the ISS and the jettison candidate as well as impacts to ISS Visiting Vehicle operations, and also provide the recommended trajectory parameters (direction, dV, etc.) required to ensure safe jettison per Section 4.

The ISS Program, in coordination with the ISRP and TOPO groups, will make the determination of a sufficiently conservative range of BN estimates for all jettison candidate analysis based on provided mass and dimensions. Attitude control systems and / or deployable subcomponents, such as solar arrays, may be taken into account for operational BN estimation, but should not be relied on to determine safe relative motion with the ISS unless sufficient fault tolerance of those systems can be verified to the ISRP. Assumptions for the appropriate ISS BN for relative motion analysis will be made on a case-by-case basis, taking into account a conservative estimate of the average configuration of the ISS in the proposed jettison timeframe.

If the determination of an initial jettison candidate departure trajectory through an image analysis technique is needed, the NASA Astromaterials Research and Exploration Science Division /XI must be involved in the pre-jettison planning of video views that will be used for the analysis. Post-jettison, NASA/CM4 will be responsible for informing USSPACECOM of the best estimate of real-time jettison direction and velocity.

***ISS Visiting Vehicle Traffic***

The NASA Trajectory Branch/CM4 will be responsible for assessing potential conflicts between the trajectories of any jettison candidate and other visiting vehicles per Section 4.1-5.

***EVA: ISS Structural Clearance and Controllability***

The NASA Crew and Thermal Systems Division Operations Branch/EC, NASA EVA Operations Branch/CX3 and the NASA EVA Office/XX will be responsible for developing EVA jettison techniques for all objects to be jettisoned during USOS based EVAs and RSC-E EVA experts will develop these techniques for all objects jettisoned during RS based EVAs. In both cases, the responsible organizations will coordinate with their counterparts in Russia or the US (respectively) through the appropriate Joint Operations Panels (JOP) or the Joint EVA Working Group (JEWG). Additionally, the EVA community will work with the responsible ISS and Flight Operations Directorate (FOD) organizations in verifying that the initial trajectory of the jettison candidate(s) clears all ISS and ISS Visiting Vehicle structures in accordance with the requirement in Section 4.1-3.a.

***Robotics: ISS Structural Clearance***

The NASA ISS Robotics Integration Office/OM7, with the participation of the implementing robotic team, will be responsible for coordinating the integrated analyses required for all jettisons via robotic elements or EVA jettison from a robotic arm. The integrated analysis results shall include consideration for timely and appropriate analysis of the robotics element for inclusion in hazard assessment, engineering development, testing, and EVA training runs, as well as verification that the initial trajectory of the jettisoned object clears all ISS and ISS Visiting Vehicle structures in accordance with the requirement in Section 4.1-3.b. The Canadian Space Agency (CSA) and Japan Aerospace Exploration Agency (JAXA), respectively, will be responsible for assessing any loads and dynamics issues associated with the use of the Space Station Remote Manipulator System (SSRMS), Special Purpose Dexterous Manipulator (SPDM), and Japanese Experiment Module Remote Manipulator System (JEMRMS) in the course of proposed jettison activities.

***Safety***
The owner of the jettison candidate will be responsible for performing safety assessments on the hardware itself, in all configurations that are associated with the jettison. Such configurations will potentially include off-nominal states such as the condition after the venting of pressurized containers or the discharge of batteries, per the requirements of Section 4.1-2 of this policy. Ballistic path, EVA, and ground hazard assessments will be performed by the specialty teams designated in this policy. The ISRP, with IP participation, will work with the VIPER team and the aforementioned specialty teams designated in this policy to ensure analysis input parameters are accurate and sufficiently fault-tolerant.

All assessments will be provided to the ISRP as hazard reports in accordance with the safety review process documented in SSP 30599 and SSP 51721. Controls and verifications must be identified for each hazard, and the controls must ensure compliance with the requirements of this policy. Review and approval of hazard reports will be performed by the ISRP at least one month prior to the Stage Operations Readiness Review (SORR) covering a planned jettison operation. For jettison operations not identified early enough to be included in the IDRD, review and approval of the hazard reports will be made within the IMMT forum in conjunction with the ISRP.

The NASA ISS Safety and Mission Assurance Office/Program Risk Office/OE, a safety organization representative for the partner conducting the jettison, and a representative for the partner whose item is to be jettisoned, will all be participants in the IMMT.

## 6.0 AUTHORITY

For jettison candidates that demonstrate compliance with all Jettison Policy criteria outlined in Section 4, the final decision to proceed with jettison operations will be made by the MSEICB. In the case of jettison candidates, which do not meet all criteria outlined in Section 4, the final decision to proceed with implementation of a jettison operation will be made by the SSCB, or in the case of operations affecting near-term tactical operations after publication of the IDRD, by the IMMT. All jettison candidates are still subject to the aforementioned ISRP safety review process, which has a series re-flight option.

The final jettison date and scheduling of all candidates is subject to review through the ISS Trajectory/CM4, VIPER/OM3, and Safety and Mission Assurance/Program Risk Office/OE to ensure that each planned jettison meets the requirements in Section 4 and that real-time ISS Visiting Vehicle traffic scheduling, ISS configuration, and planned ISS attitude support safe jettison operations.

## 7.0 PRODUCT CONTROL

N/A

## 8.0 APPEALS

Should any party wish to appeal the decision of the MSEICB, the appeal will be brought back to the MSEICB for reconsideration. If the appeal is not resolved at the MSEICB, then it may be brought directly to the SSCB. For real-time jettison requests via the chit process, appeals will be addressed by the IMMT.

**APPROVALS**

| | |
|---|---|
| Gabriele Mascetti<br>Manager, ISS Board Representative<br>Italian Space Agency | Date |
| Luc Dubé<br>ISS Program Manager<br>Canadian Space Agency | Date |
| Bernardo Patti<br>ISS Programme Manager<br>European Space Agency | Date |
| Junichi Sakai ISS Program Manager<br>Human Spaceflight Mission Directorate<br>Japan Aerospace Exploration Agency | Date |
| Alexey A. Strelnikov<br>Director, Department of Human Space Programs<br>State Space Corporation<br>“Roscosmos” | Date |

## APPENDIX A: JETTISON APPROVAL PROCESS FLOW CHART

**VIPER notified of Jettison Requests from FOD or OZ (Typically Launch-7 months)**

**Data Gathering: (Launch-7 months to Launch-6 months)**

- **Gather data on the candidate from OZ / EVA teams for analyses and assessments: mass, dimensions, materials details, propulsive systems, attitude control, power systems, deployable subcomponents, deploy method, deploy location, ops concept, End of Mission (EOM) safing plan, etc.**

**Initial Assessment: (Launch-6 months through Launch-5 months)**

- **Perform Ballistic Number (BN) assessment based on candidate mass and dimensions (1 week)**
- **Perform trackability assessment based on candidate's mass, dimension, and materials data**
- **Assess if planned jettison location and vector has been previously used or analyzed, and are still valid for current ISS configuration**
- **Assess if candidate meets NASA-STD-8719.14 for orbital debris generation and ground population risk (up to 3 months)**
    - **Candidates with mass < 5kg meet NASA-STD-8719.14 requirement for ground population risk**
    - **Candidates with EOM passivation plan to deplete all on-board stored energy sources meet NASA-STD- 8719.14 requirements for orbital debris generation (applicable to US payload and ISS hardware only)**
- **Assess candidate details for compliance to jettison policy Express Authorization Criteria (EAC) based on gathered details and completed initial assessments (1 week)**
    - **Candidates with a metallic cross sectional area on three orthogonal sides ≥ to that of a sphere with diameter 10 cm (78.5 cm$^2$) meet EAC for trackability**
    - **Candidates whose jettison location, vector, and method have previously been analyzed and approved meet EAC for ISS structural clearance, provided no ISS configuration change invalidates that analysis**
    - **Candidates with a BN lower than those listed in Table 4.1-4 for the associated deploy velocity, do not pose risk of re-contact to ISS during nominal operations.**
    - **Candidates that have propulsive systems, tethers, deployable sub-components, or other characteristics that might necessitate additional constraints do NOT meet EAC**

**ISRP Vetting & Detailed Analyses: (Launch-5 months through Launch-2 months)**

- **ISRP vets credible failure scenarios that may impact any initial conditions used in the detailed analyses (3 weeks)**
- **Detailed analyses performed, if deemed necessary, as detailed in section 4 of jettison policy**
    - **MAGIK team (within ISS Program Systems Engineering and Integration Office) analyzes the proposed jettison location and provides a jettison vector range that ensures that worst-case deviation from jettison vector, remains clear of ISS structure. (3 weeks)**
    - **TOPO completes recontact analysis for candidates being jettisoned from ISS, and minimum deploy altitude analysis for candidates being jettisoned from ISS Visiting Vehicles at altitudes above ISS (up to 4 months)**

**Multi-lateral Systems Engineering and Integration Control Board (MSEICB): Jettison Authorization (Launch-2 months to Launch-1 month)**

- **Candidates are presented at the MSEICB to have jettison authorization granted by NASA and all International Partners**
    - **Candidates that meet all jettison policy requirements (including all EAC) may be granted jettison authorization by MSEICB representatives via email concurrence out-of-board.**
    - **Candidates that do not meet one or more jettison policy requirements may still be granted jettison authorization, but may be required to receive authorization through the Space Station Control Board (SSCB) or the ISS Mission Management Team (IMMT).**

**SSCB or IMMT: Final Jettison Authorization (Launch-1 month to Launch)**

- **Candidates not authorized by the MSEICB, must have their authorization granted by the SSCB or the IMMT.**

APPENDIX B: JETTISON APPROVAL REFERENCE DOCUMENTS

NASA-STD-8719.14 Process for Limiting Orbital Debris
https://standards.nasa.gov/standard/osma/nasa-std-871914

UNCOPUOS Space Debris Mitigation Guidelines (June 2007)
http://www.unoosa.org/oosa/oosadoc/data/documents/2010/stspace/stspace49_0.html

IADC Space Debris Mitigation Guidelines (March 2020).
https://www.iadc-home.org/documents_public/view/id/82#u

SSP 51721 ISS Safety Requirements Document
https://edms.iss.nasa.gov/EDMS_SS/contenttransfer?objectID=0900393080466414

SSP 30599 Safety Review Process - International Space Station Program
https://tdglobal.ksc.nasa.gov/servlet/sm.web.Fetch/SSP_30599F_Safety_Review_Process__002_.pdf?rhid=1000&did=932704&type=released

ISS Program Office Best Practices for Satellite Payload Developers
*See Appendix C for the complete text of this document*

APPENDIX C: ISS PROGRAM OFFICE BEST PRACTICES FOR SATELLITE PAYLOAD DEVELOPERS

# International Space Station Program Office Best Practices for Satellite Payload Developer

## Scope

This document is intended to be used as a resource for Payload Developers (PD's) who intend to deploy satellites from the International Space Station (ISS), ISS Visiting Vehicles, or other ISS assets. This document will focus on ISS Safety and Jettison Policy requirements, and what design choices PD's can make to simplify the jettison approval and authorization process and minimize risk to ISS and its visiting vehicle fleet. The ISS Jettison Policy was developed to limit risk to ISS – both directly by ensuring that objects jettisoned from ISS do not become collision hazards and indirectly by reducing risk that jettisoned objects create additional on-orbit debris.
In addition to this document, the author also recommends that Payload Developers review the guidelines and best practices developed by the Space Safety Coalition (SSC) at https://spacesafety.org/. The best practices recommended by the SSC promote responsible space safety for all space industry stakeholders, and should be reviewed by all satellite payload developers.

## The ISS Jettison Policy

Anything planned to be jettisoned or deployed from the ISS or any ISS Visiting Vehicle must show compliance with the various safety requirements documented in ISS Partner Program Directive (PPD) 1011, the ISS Jettison Policy. The ISS Program's analysis and approval process for jettison candidates typically takes roughly 3-6 months, depending on the complexity of the jettison candidate. The following sections will outline the requirements of the Jettison Policy and how payload developers can design to easily meet these requirements.

## Limiting Orbital Debris

One of the primary functions of the ISS Jettison Policy is to promote the safety of the ISS and other on-orbit assets by ensuring objects jettisoned do not substantially contribute to the debris environment.

The Jettison Policy requires all candidates be trackable by the Space Surveillance Network. While trackability can be assessed on a case by case basis, the general rule of thumb is that any object with a metallic cross sectional area greater than or equal to 100 $cm^2$ on three orthogonal sides is trackable. Additionally, metallic appendages and antennas will increase the Radar Cross Section (RCS) of a satellite beyond the geometric dimensions, making satellites with larger antennas or appendages more favorable for tracking. The ISS Program strongly discourages deployment of satellites smaller than this. In addition to design considerations, payload developers are strongly encouraged to establish communications with JSpOC early by registering the satellite on space-track.org and sharing contact information. Registration can be found at the bottom of the main space-track.org home page, under the link "Register Your Satellite / Payload with 18 SPCS" (note that space-track.org access requires registration via email/password setup). This registration enables the 18th SPCS to communicate directly with the PD for Two Line Element (TLE) sharing, conjunction assessments, etc. Their recommendations on Cubesat development and operation can be found in the 18th Space Control Squadron Cubesat Recommendations:
https://swfound.org/media/205965/mckissock_cubesat_recommendations_aug2017.pdf.

In addition to trackability, the policy also requires candidates demonstrate they do not pose a significant risk of on-orbit fragmentation. The simplest way to accomplish this is for Payload developers to ensure any stored energy systems will be completely depleted at end of mission. This includes removing energy in the form of electrical, pressure, mechanical, or chemical. This process is referred to as passivation. For a more in-depth explanation of NASA passivation requirements, refer to NASA Technical STD. 8719.14. The NASA Orbital Debris Program Office (ODPO) has provided guidance that cubesats 3U and smaller with orbital lifetimes less than 25 years do not need to meet the passivation requirement. In addition to passivation, payload developers should consider the expected mission of a satellite and tailor operational altitude accordingly. Satellites with 1-2 months of science objectives, for example, may not be suitable for deployment from ISS altitudes where orbital lifetimes can be 6 months to several years (depending on solar activity). Similarly, satellites released from external deployers on ISS visiting vehicles are expected to remain on-orbit for multiple years. Satellites with 6 months to 1 year of science objectives may not be suitable for such deployments. Tailoring the satellite's altitude, and thus orbital lifetime, helps reduce the likelihood of on-orbit debris-generating collisions.

Finally, Payload Developers should be cognizant of the risk their satellite may pose to the ground population following atmospheric re-entry. The requirement to limit this risk can be found in NASA Technical Standard 8719.14. Any object which survives the harsh conditions of re-entry and maintains a kinetic energy greater than 15 Joules could potentially injure someone on the ground. Each of these surviving objects contributes toward a total ground casualty risk, which must be lower than 1:10,000 per the aforementioned 8719.14 requirements. An excellent resource for assessing ground impact risk of a satellite is NASA's Debris Assessment Software (DAS). This software, along with instructions, is publicly available from NASA's Orbital Debris Program Office (ODPO): https://www.orbitaldebris.jsc.nasa.gov/mitigation/das.html. DAS is an excellent resource since it also includes tools to assess on-orbit lifetime and compliance with other NASA STD. 8719.12 requirements.

## Limit Risk of Collision with ISS and Visiting Vehicles

The International Space Station (ISS) Program considers collision between a previously deployed satellite and the ISS a catastrophic hazard. There are a number of detailed requirements in the Jettison Policy dealing with re-contact risk and how it is assessed. The following sections will provide more detail on the process of how that risk is assessed and recommend actions the PD can take to mitigate this risk.

## Deploy Timing and Visiting Vehicle Considerations

Payload developers should be aware that satellite deployments from ISS are scheduled to avoid potential interference with ISS visiting vehicle traffic. The following requirements documented in the ISS Jettison Policy ensure sufficient time to determine the jettison candidate's orbital parameters and assess effects on any visiting vehicle operations:

a. For jettison events comprising more than 3 candidates, jettison shall be scheduled such that there is at least 6 days of separation from the final jettison date to the next visiting vehicle event.
b. For jettison events comprising 3 or fewer candidates, jettison shall be scheduled such that there is at least 4 days of separation from the final jettison date to the next visiting vehicle event.
c. This minimum separation time may be reduced further on a case specific basis if case specific analysis demonstrates that it is safe to do so.

These requirements ensure that on-orbit tracking data is available for any objects deployed from ISS prior to potential collision with any incoming or outgoing ISS visiting vehicles. Visiting vehicle events are defined on a case by case basis dependent on each vehicle's standard rendezvous and departure profiles, but in most cases will be the dock / berth and undock / unberth dates. In the case of visiting vehicle post-departure planning, jettisons may be performed immediately following confirmation of the full re-entry of the departing vehicle. These constraints typically don't apply to satellites deployed via Visiting Vehicle above ISS, though there can be exceptions if the satellite(s) to be deployed have propulsive systems capable of moving the satellite to an orbit that could interfere with ISS visiting vehicle operations. Satellite developers should be aware of these constraints, since they will impose black-outs on specific deploy dates depending on Visiting Vehicle traffic.


Figure 1: Two 3U "Dove" Cubests being deployed from the NanoRacks Cubesat Deployer (NRCSD) on the end of the JEM RMS, Feb 2014

## Natural Atmospheric Decay and ISS Re-Contact Risk

In the case of satellites that lack any method of controlling their orbital altitude, simple orbital mechanics analysis can be sufficient to demonstrate that the risk of re-contact with the ISS is sufficiently controlled. This orbital mechanics analysis is performed for all jettison candidates: The VIPER team provides input parameters to the Trajectory Operations and Planning Officer (TOPO) team, who perform relative motion analysis of the candidate with respect to the ISS. Alternatively, the PD themselves may provide relative motion analysis results to the VIPER and TOPO teams for review and concurrence. Input parameters include:

- ISS ballistic properties, which are consistent and predictable: conservatively the ISS Ballistic Number (BN) is approximately 100 kg/m$^2$ at low solar beta angles
  - The planned timeframe of jettison can be taken into account if necessary to provide some relief (beta cutouts) for candidates with BN's higher than 100 kg/m$^2$ since ISS BN is a function of Beta, and increases in magnitude as beta angle increases
- The planned jettison location, direction, and deploy speed
  - In cases where sufficient fault tolerance cannot be demonstrated for the deploy mechanism's deploy speed (dV), the worst case (slowest) deploy speed is typically assumed
- The jettison candidate/satellite's ballistic properties
  - The ballistic properties of the candidate can vary significantly: Ballistic Number is dictated by mass and dimensions of the candidate, but the flight orientation of the candidate is assumed to be an average of the three orthogonal faces of a satellite unless analysis demonstrates otherwise. The ISS Program considers this average BN for its baseline assessment of re-contact hazard. In some cases, the ISS Program will request analysis with a BN calculated using the average of only the two smallest orthogonal faces of the satellite – this case is considered the "worst Avg" BN, and is used to help bound re-contact results in some cases.

The Ballistic Number referenced above is in reference to a mass/area ratio commonly used to calculate drag on an orbiting object. Drag forces on orbit are calculated the same as for aircraft:

- $F_D = \frac{1}{2}\rho v^2 C_D A$, where:
  - $F_D$ is the drag force on any object moving through a fluid
  - $\rho$ is density of the fluid / atmosphere
  - $v$ is velocity of the object
  - $C_D$ is Coefficient of Drag – almost always assumed to be ~2.0 based on observation for ISS applications
  - $A$ is cross sectional area – this is the area of an object that is directly interacting with particles in the velocity vector, creating drag

For orbital drag calculations, we are most interested in the acceleration due to drag (F = ma), so we rearrange the above equation and solve for acceleration due to Drag:

- $a_D = \frac{\rho v^2 C_D A}{2m}$

The Ballistic Number combines constant characteristics of the object into one parameter:

- $BN = \frac{m}{C_D A}$

Comparing the equation for BN to the acceleration due to Drag equation above, it is simple to see the inverse relationship between BN and Drag: The higher the BN, the lower acceleration due to drag the object experiences.

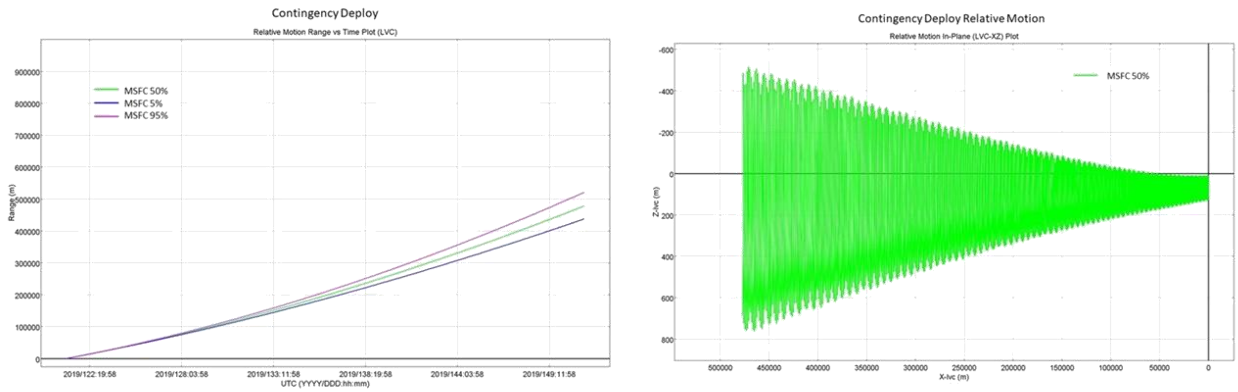


Figure 2: Typical ISS relative motion analysis results. Left plot is range vs. time; right plot is in-plane relative motion (the local XZ direction). These results demonstrate a case where the object in question does not return to the ISS

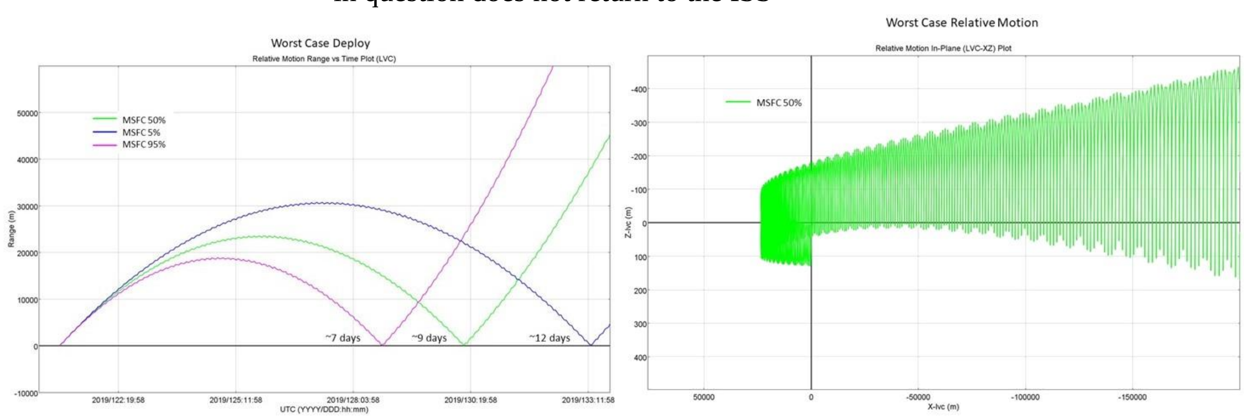


Figure 3: ISS relative motion analysis results. Left is range vs. time, right is in-plane relative motion (the local XZ direction). These results demonstrate a case where the object in question appears to return to the ISS within 7-12 days following deployment

**Designing Satellite to Minimize Re-Contact Risk:**

Since BN directly influences the speed at which an object decays through the atmosphere, it is in the best interest of a satellite PD to demonstrate that the BN of their satellite is less than that of the ISS if the satellite is being deployed from ISS. If this can be demonstrated, the satellite will decay <u>faster</u> than the ISS, and there will be little or no re-contact risk with the ISS.

Some satellites are designed such that the previously described "worst case" BN already meets this criteria: the BN calculated using the average of the two smallest orthogonal areas on the satellite is already less than the BN of the ISS. In this case, verification that the passive re-contact criteria in the ISS Jettison Policy is a simple calculation using the equations above to demonstrate the satellite's BN is less than 100 $kg/m^2$, which is the ISS BN under conservative environmental conditions.

Alternatively, in some cases PDs have a satellite whose total average Ballistic Number is less than ISS, but the worst case BN is not. In those cases, the PD has the option of coordinating with the ISS Program on 6 degree of freedom (6DOF) analysis to demonstrate that without attitude control, the satellite will not orient itself into this "worst case" BN orientation. This analysis is expected to be provided by the Payload Developer, with input assumptions agreed to with the ISS Program Office. Many Aerospace software packages, such as STK, SNAP, etc., offer 6DOF analysis capabilities. The objective of this type of analysis is to demonstrate that the "worst case" tumbling configuration is not a realistic assumption for re-contact analysis. Figure 4 illustrates the yaw, pitch, and roll results of one such analysis, demonstrating that random tumble is a more appropriate assumption for this satellite.

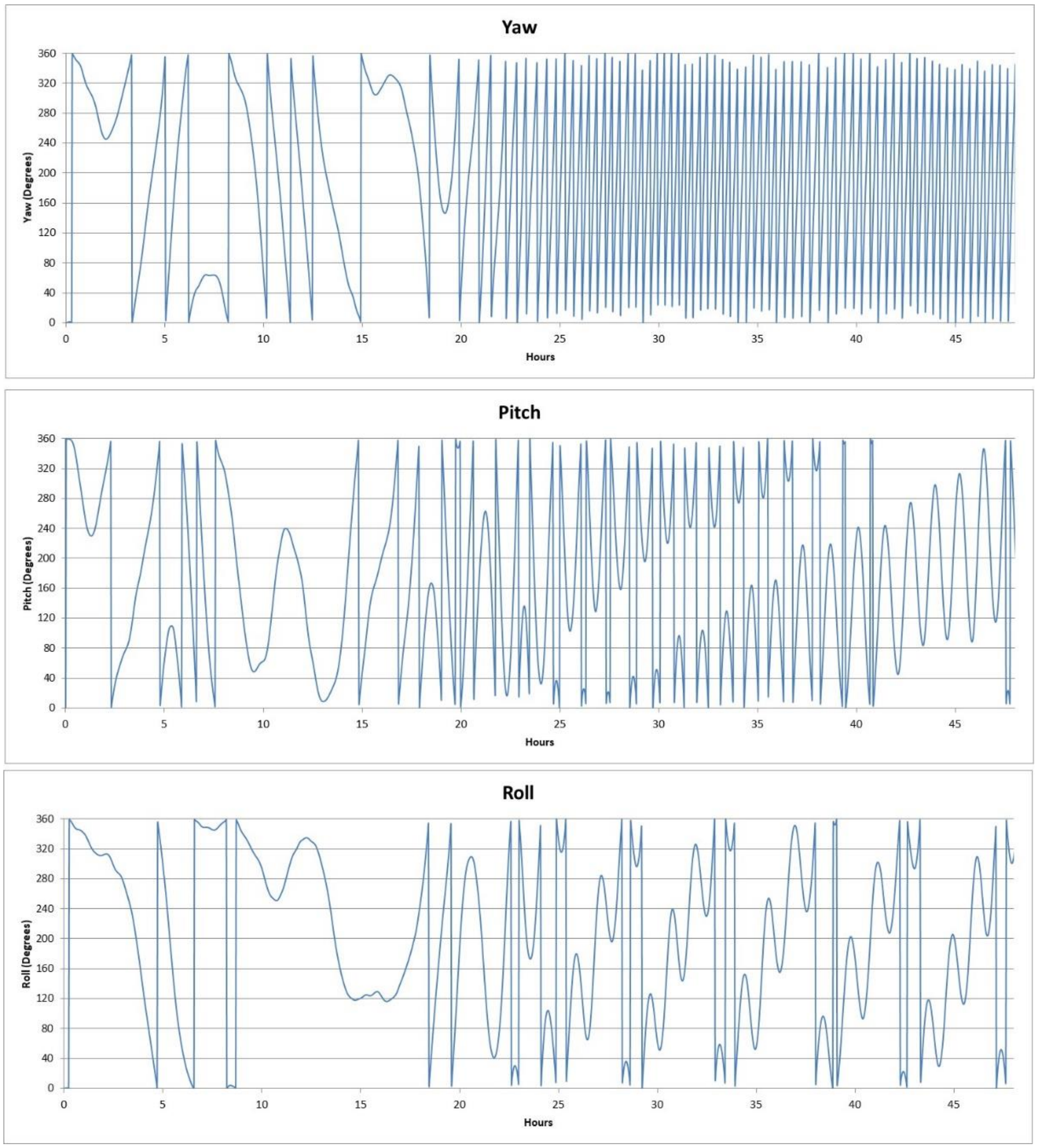


Figure 4: Sample 6 Degree of Freedom Analysis Results (Tumble)

Note that the 6DOF analysis above is actually run for 7 days; however, for clarity the data is shown here for only the first 48 hours. It can be seen that the yaw, pitch, and roll values of the payload in the analysis above continue to fluctuate constantly throughout the duration of the analysis without "settling into" one particular angle on any axis, which would indicate attitude stabilization. Based on the results of this type of analysis, the VIPER and TOPO teams are more confident using the less conservative random tumble BN for the satellite (or an operational BN, if available): This BN is calculated using the average of all 3 orthogonal sides of the satellite rather than just the smallest two. In cases where one axis does stabilize per 6DOF analysis, VIPER and

TOPO specialists can still use this information to develop a more realistic Ballistic profile for the satellite than the typical random tumble.

If a satellite's BN is still higher than ~100 kg/m$^2$, additional risk mitigation techniques may be used to reduce risk of re-contact with ISS, but often rely on deployment constraints on the satellite. In these cases, verification of Jettison Policy re-contact requirements is accomplished via relative motion analysis coordinated by VIPER and performed by the TOPO office. In all cases, Ballistic Number and re-contact analysis is presented to the ISS Program and International Partners for review and jettison authorization.

Note that the Ballistic Number recommendations thus far assume satellites are being deployed from ISS. Satellites deployed from visiting vehicles above ISS are subject to less stringent constraints on BN. Currently, the ISS Program requires satellites deployed above ISS be deployed at least 45 km above ISS average altitude. This altitude constraint ensures sufficient time to develop tracking on the object before it decays to ISS altitudes and sufficient crossing speed with respect to ISS to calculate a Probability of Collision (PC). The analysis which defines the 45 km limit protects for satellites with BN as low as 10 kg/m$^2$. Candidates with BNs lower than 10 kg/m$^2$ will require additional analysis, and likely would drive a deployment limit higher than 45 km above ISS. While there is not an official upper BN limit for satellites deployed from visiting vehicles, it is recommended to consider the desired on-orbit lifetime and tailor BN appropriately.

The re-contact analysis described thus far assumes either 1) The satellite jettison candidate does not have attitude control or 2) The satellite's attitude control has failed to activate. In cases where a satellite possesses attitude control, the PD must provide the planned flight orientations of the satellite for additional re-contact analysis to be performed by TOPO. This delivery should include information on the expected orientation(s) of the satellite, with durations for each. If additional relative motion cases are deemed necessary, they will assume that attitude control is activated and functional, and check the operational BN(s) of the satellite for any ISS re-contact concerns.

Figure 5: Several TechEdSat satellites have been deployed from ISS over the past few years, many using exo-brake devices to increase the drag of a satellite (concept art)

**Propellant Systems, Tethers, Sub-Deployable Satellites, etc.**
The aforementioned re-contact analysis assumes a passive satellite: it does not take into account any systems on the satellite that could potentially change its orbit. Any mechanism that has the capability to change the orbit of the satellite (or release another satellite into a different orbit) brings with it the risk of collision with ISS or other NASA assets that must be controlled. The most common of these capabilities is a chemical, electrical, or pressure based propulsion system, though sub-deployable satellites and tethers have been assessed and approved for deployment from ISS as well. For simplicity, these types of systems will be referred to as "propulsive systems" in the following sections. Section 4.2 of the ISS Jettison Policy is specifically written for satellites with propulsive capability. This section outlines three primary requirements for propulsive satellite owners:

**a. Establish a data sharing process with the 18SPCS and NASA/TOPO**

While a Space Situational Awareness (SAA) agreement with 18SPCS is strongly encouraged for all ISS satellite jettison candidates, it is now a requirement for propulsive satellites to be jettisoned from ISS. Additionally, propulsive jettison candidates are required to sign an agreement with NASA to document the data exchange process between TOPO and satellite mission operations team. This agreement is typically in the form of a Payload Integration Agreement (PIA), and it ensures that NASA has insight into the progress satellites have made toward the Responsible and Safe Space Operator criteria as well as capability to provide Go/No-Go for satellite propulsive maneuvers when necessary.

**b. Demonstrate that the satellite operators are Responsible and Safe Space Operators (RSSO)**

The intent of the recently-added RSSO requirements is to provide payload developers an opportunity to demonstrate that they can operate independent of NASA guidance without impacting ISS safety. These requirements include demonstrations that the satellite can accurately orient and hold attitude for translational maneuvers, that the satellite achieves the expected dV for translational maneuvers, that the mission operations team can output accurate pre and post-burn state vectors, and that the mission operations team has a Collision Avoidance (CA) process in place. A Collision Avoidance process typically includes the following:
Key Components to a Collision Avoidance Process:

1. Frequency the mission ops team plans to review conjunction data. For example, is this done at a minimum of every 8 hours when the Mission Director is checking the status of a vehicle, or done once per day by a trajectory specialist.
2. Criteria to determine if conjunction data gets passed to the operations team. For example, will the sharing agreement with 18SPCS require delivery of messages on all conjunctions within a specific volume, above a certain Probability threshold, or under a set amount of time to closest approach.
3. Criteria used to determine if a conjunction needs to be avoided using a translational maneuver. Robust CA processes have criteria based on an acceptable margin of risk to vehicle/crew – industry standard is typically Pc > 1E-4, but ISS uses Pc > 1E-5.
4. A timeline of decision points in the CA process - including when an emergency maneuver is deemed necessary, built, and executed. The timeline should be based on how often conjunction data is being reviewed, the minimum time required to build a burn (times

can be shorter if pre-built maneuver options are available), and how much time is required to uplink and execute the maneuver.

5. When orbit maintenance/raising/lowering burns are planned, what criteria is used to ensure those burns are safe from conjunction.

Aside from a CA process, the requirements in this section cannot be verified pre-flight, thus the aforementioned signed PIA agreement will keep NASA appraised of the satellite's RSSO status once on-orbit.

**c. Operate the satellite such that it cannot interfere with ISS operations.**

The ultimate goal of all ISS Jettison Policy propulsive satellites requirements is to limit risk of collision between the jettison candidate and ISS. Mission operators who have successfully demonstrated RSSO status on-orbit will themselves be responsible for ensuring that their satellite does not enter the ISS Conjunction Notification Volume. Satellites whose mission operations team have not demonstrated RSSO status will be required to meet part A of requirement 4.2-3 Limit risk of re-contact with ISS:

a. If a propulsive jettison candidate has not met the criteria in Section 4.2-2 to be considered a Responsible and Safe Space Operator, or the satellite loses the ability to meet those criteria, prior to planning any on-orbit maneuvers the satellite's missions operations team shall demonstrate that they do not pose a collision hazard to the ISS or visiting vehicles.
   1. While operating below ISS altitude, the jettison candidate shall not modify its orbit when there exists a possibility for visiting vehicle interference.
   2. Propulsive candidates shall demonstrate that within credible systems failure scenarios as defined by the payload developer and International Space Station Safety Review Panel (ISRP), the candidate cannot maneuver itself into the ISS CNV within 10 days of failure occurrence.
   3. While the propulsive jettison candidate is within, or has the ability to enter, the average ISS altitude range (bounded by perigee and apogee), TOPO analysis and input shall be required for a Go/No-Go prior to orbit modifying events to control hazards identified above.

Parts 1 & 3 of requirement 4.2-3 are operational requirements. Compliance can be achieved by the PD making agreements with ISS flight operators at NASA that the satellite plans to operate in a way that will not impact ISS operations. These agreements are coordinated through VIPER & TOPO, and typically include a timeline of expected altitudes the satellite is planned to fly, along with any necessary constraints to control collision hazard with ISS. Since these satellites pose a unique collision hazard to ISS, Payload Developers are responsible for providing correspondence to the safety community agreeing to follow these constraints, as well as a PIA documenting communications channels with NASA TOPO. That correspondence will be used as verification of a control in the ISS Collision Risk Hazard Report. It is recommended that satellites plan to operate well below or well above (for satellites released from external deployers mounted on ISS visiting vehicles) the operational altitude range of the ISS, which is roughly 395 km to 425 km.

Actively maneuvering to cross the ISS operational altitude range should be avoided whenever possible, unless the satellite can demonstrate 2 fault tolerance and must work functionality in the propulsion systems / deployment mechanisms / tether system / etc. A Payload Integration Agreement (PIA) documents the real time communications process between Payload Developer and VIPER/TOPO to coordinate any necessary real time decisions.

Compliance with part 2 of Requirement 4.2-3.b is related to satellite design and fault tolerance. The ISRP considers any collision between ISS and a jettison candidate to be a catastrophic hazard, which per NASA safety guidelines requires at least 2 fault tolerance to control. ***The most straight forward way to show compliance with part B (and thus NASA safety requirements) is to demonstrate 2 fault tolerance against inadvertent thruster firing once the satellite has been activated***; however, many satellites do not have the resources for 3 fully redundant computer systems. If 2 fault tolerance cannot be demonstrated, relative motion analysis between the satellite and ISS will be required assuming the "worst case" thruster firing scenario, as agreed to with the ISS safety community, is an acceptable way to demonstrate compliance with this requirement. Typically this relative motion analysis is performed by a NASA TOPO representative, with input from the Payload developer and the safety community. The input required for this analysis is typically based on the realistic worst case thruster failure scenario, with a goal of finding an "effective dV." This "effective dV" will bound the possible thrust profile, timeframe, and duration of an inadvertent thruster firing. The following sections will provide recommendations that will minimize re-contact risk to the ISS.

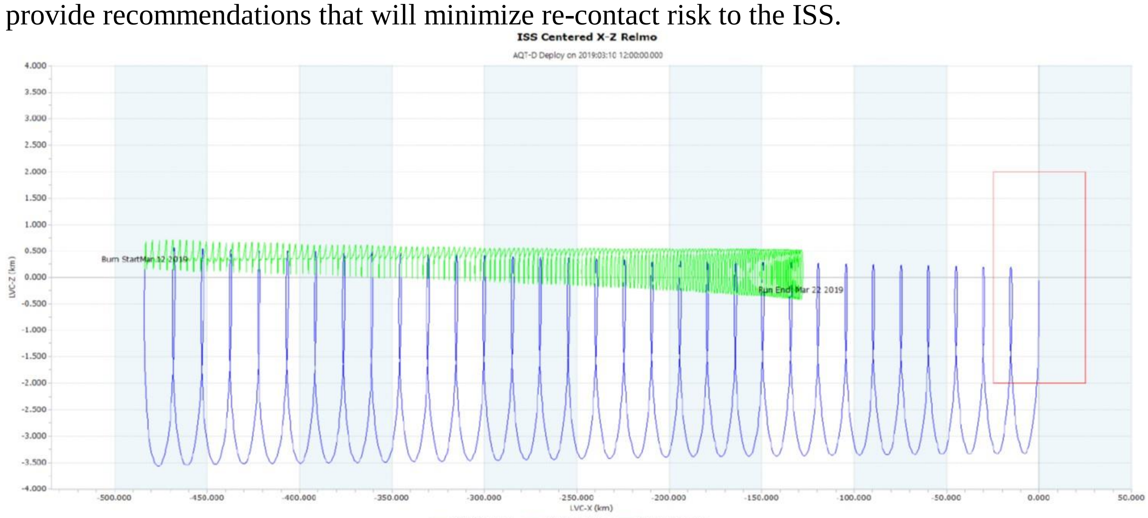


Figure 6: Relative Motion Analysis Results for Propulsive Satellite

Figure 6 illustrates a typical relative motion analysis for a propulsive satellite deployed from ISS: The blue segment demonstrates separation from ISS, which is static at the origin. In this case the satellite has an inhibit against thruster activation for the first 48 hours post deployment from ISS, at which point it is assumed that the satellite inadvertently performs a maximum dV burn (18 minutes) posi-grade back toward ISS, represented by the green segment. These types of analyses (and the input assumptions guiding them) are instrumental in the ISS Safety and Program Office risk assessment and approval process.

The following sections will provide recommendations on approaches that payload developers can take to minimize the "effective dV" that could be applied to the satellite in the credible worst case inadvertent thruster firing scenario; however, these recommendations are not comprehensive: Any method of reducing the "effective dV" a satellite could achieve in a failure scenario could potentially mitigate the re-contact risk with ISS and demonstrate compliance with the Jettison Policy.

## Satellite Design Considerations

The following sections are intended to provide NASA guidance on satellite design choices, with the intent of meeting the ISS Jettison Policy criteria outlined in the above sections.

### DFMR

Design for Minimum Risk (DFMR) is an alternate approach to failure tolerance using the safety related properties and characteristics of the design to reduce the associated risk to an acceptable level. Hazards related to DFMR are controlled by the safety related properties and characteristics of the design, such as margin or Factors of Safety (FOS), that have been baselined by ISSP requirements.

In some design areas, failure tolerance cannot be achieved in a logical manner without making the design so complex or expensive that it cannot perform its function. In these cases, creating a design that meets a certain FOS, for example, provides a comparable control to failure tolerance. DFMR can provide the equivalency of either one or two failure tolerance, provided specific design features (as defined by the appropriate engineering technical authority and concurred by the ISRP), are fully implemented and verified. Examples of areas where DFMR is acceptable include structures, glass, pressure vessels, pressurized lines and fittings, pyrotechnic devices, mechanisms in critical applications, material compatibility, and flammability. Hazard controls related to these areas are extremely critical and warrant careful attention to the details of verification of compliance on the part of the end item provider.

## Inhibit Scheme

VIPER recommends that payload developers design their satellites with additional inhibits between satellite activation and propulsive system activation. Historically, satellite developers have had difficulty demonstrating sufficient control against inadvertent activation of the propulsive system after satellite activation (even without any commanding to begin thruster firing / satellite deployment /etc.), thus the ISS safety community has constrained satellite activation itself (or required removal of all propellant, sub-deployables, or tethers on the satellite) in order to control the ISS re-contact hazard. A physical inhibit between satellite activation and propulsive system activation could allow the satellite to activate and begin science objectives much sooner, without need for an entire satellite activation inhibit against ISS re-contact.

It is for this reason that the VIPER team strongly recommends PDs develop fault trees for their propulsive systems. It is critically important during the safety review process for the PD to be able to identify credible failure scenarios and determine the number of faults necessary for these failures to happen. Similarly, payload developers that successfully perform Computer Based Control System (CBCS) or use hardware that has been reviewed through CBCS analysis can more confidently be shown to meet the safety criteria of the NASA Safety community. Reference SSP 50038, *Computer Based Control System Safety Requirements*, including general requirements that must be met in all CBCS designs, requirements for “must not work” functionality (control of functions whose inadvertent operation would cause a hazard to ISS), and requirements for “must work” functionality (control of functions that must work for ISS to be safe – typically not required for small satellites).

**Command Encryption**

As a general rule, satellites with propulsive systems should have command encryption. It prevents possible issues with signal interference, and can help provide assurance that commanding to the satellite is intentional. The National Security Agency (NSA) is a good resource for recommendations on Commercial Solutions and various Capability Packages.

**Low Maximum Satellite dV**

Robotic deployment mechanisms available on the ISS generally deploy satellites at speeds between 0.2 m/s up to 2 m/s. It’s straight-forward trigonometry to determine the effective retrograde departing speed of the satellite taking into account robotic deployment angles. Knowing the effective deployment dV can provide a bounding condition for the worst case thrust needed to create a re-contact risk: the propulsive system of the satellite would have to be capable of providing dV greater than that initial effective departing speed (assuming the satellite meets the aforementioned Ballistic Number requirements of the Jettison Policy). Similarly, the process of daughter satellite deployment or tether release could induce propulsive forces on the satellite(s). As long as the total dV that can be imparted on the satellite by any of these systems is lower than the effective retrograde departing rate from ISS, it becomes trivial to demonstrate risk of re-contact is controlled and further analysis is typically unnecessary.

Figure 7: JAXA’s AQT-D satellite uses a water-based propulsive system AQUARIUS-1U (AQUA ResIstojet propUlsion System) to provide translational maneuvers and attitude control

## Thruster Layout

Thruster layout is another way that ISS re-contact risk can be reduced. One method of limiting the worst case dV that could be applied to the satellite is orienting multiple thrusters such that they are individually pointed offset from the c.g. of the satellite, but provide a total force which acts through the c.g.. These thrusters individually do not provide dV to the satellite, and thus any failure scenario which considers only a single thruster inadvertently firing cannot present a re-contact risk to ISS. Because such a configuration requires multiple thrusters fail ‘on’ to achieve dV, additional fault tolerance against ISS re-contact is achieved. Note that computing / CBCS fault tolerance may impact the viability of this solution: Satellite developers should be prepared to demonstrate that there isn’t a single failure which would lead to all engines firing simultaneously. Figure 8 shows one such satellite thruster configuration:

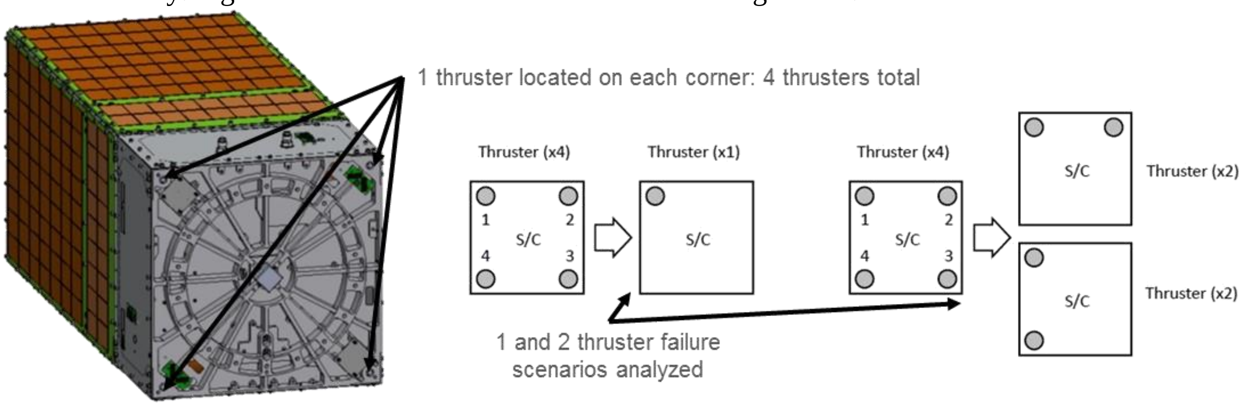


Figure 8: Satellite Center of Gravity (c.g.) Offset Thruster Configuration

Note that the thruster configurations shown in the figure above are not actually comprehensive: two thrusters failed on diagonally could contribute to a total thrust still applied through the c.g. of the satellite. It is for this reason that the ISS Program office recommends early coordination of analysis assumptions between PD and VIPER/TOPO/the safety community to ensure that the appropriate cases have been assessed.

## Attitude Control

Because re-contact with the ISS requires specific orientation when activating propulsive systems, fault tolerance in a satellite’s attitude control systems can be used as rationale that a satellite cannot realistically pose a re-contact risk with ISS. Even without 2 fault tolerance, demonstrating that the attitude control system is controlled independently from the propulsive system can provide an additional level of fault tolerance against reboost, assuming the satellite does not nominally intend to operate in an orientation that would result in a reboost in the event of a failed-on propulsive system.

Figure 9: SpinSat pre-deployment from Cyclops deployment mechanism.

**Thruster On-Time Limitations**

Thruster on-time limitations can be an effective method of limiting re-contact risk with the ISS. Many thrusters are only capable of firing for a limited amount of time, often a shorter timeframe than would be necessary to expend all available propellant on the satellite. Power budget limitations on satellite electrical systems can have a similar effect: if a satellite's power systems can only support a short duration of attitude control and thruster firing before running out of batteries, this limitation can be taken into account or the "effective dV" capability of the satellite. Alternatively, inhibits designed into the propellant system that limit the dV that can be applied to the satellite for each commanded use of the thrusters also reduces the total effective dV that can be achieved in a particular failure scenario.
These thruster limitations, if verifiable to the ISS safety community, can be used as rationale to reduce the overall "effective dV" applied to the satellite in the worst-case inadvertent thruster firing analysis scenarios. Reducing the worst case effective dV will allow satellite propulsive systems to activate and begin operation sooner: If a thruster system cannot fire long enough in a single burn to achieve a total dV greater than the departing dV from the ISS, re-contact with ISS is controlled.

**Low Impulse Thrust Systems**

Similar to thruster on-time limitations, satellites using engines that provide low impulse (such as ion thrusters) dramatically reduce the risk of re-contact with ISS since they do not quickly change the orbit of the satellite. Since significant dV takes so long to achieve for such systems, a failure would have to be stable (attitude control consistently incorrect, for example) to actually put the satellite at risk of conjunction with ISS. Additionally, in the worst case ISS would be aware of and able to respond to a failure in such a low thrust system well ahead of time if necessary, essentially eliminating the actual risk of conjunction. If the impulse of the thrust system is so low that it would take > 10 days to generate the dV required to create a re-contact risk, Requirement 3.2-3.b can be shown to be met.

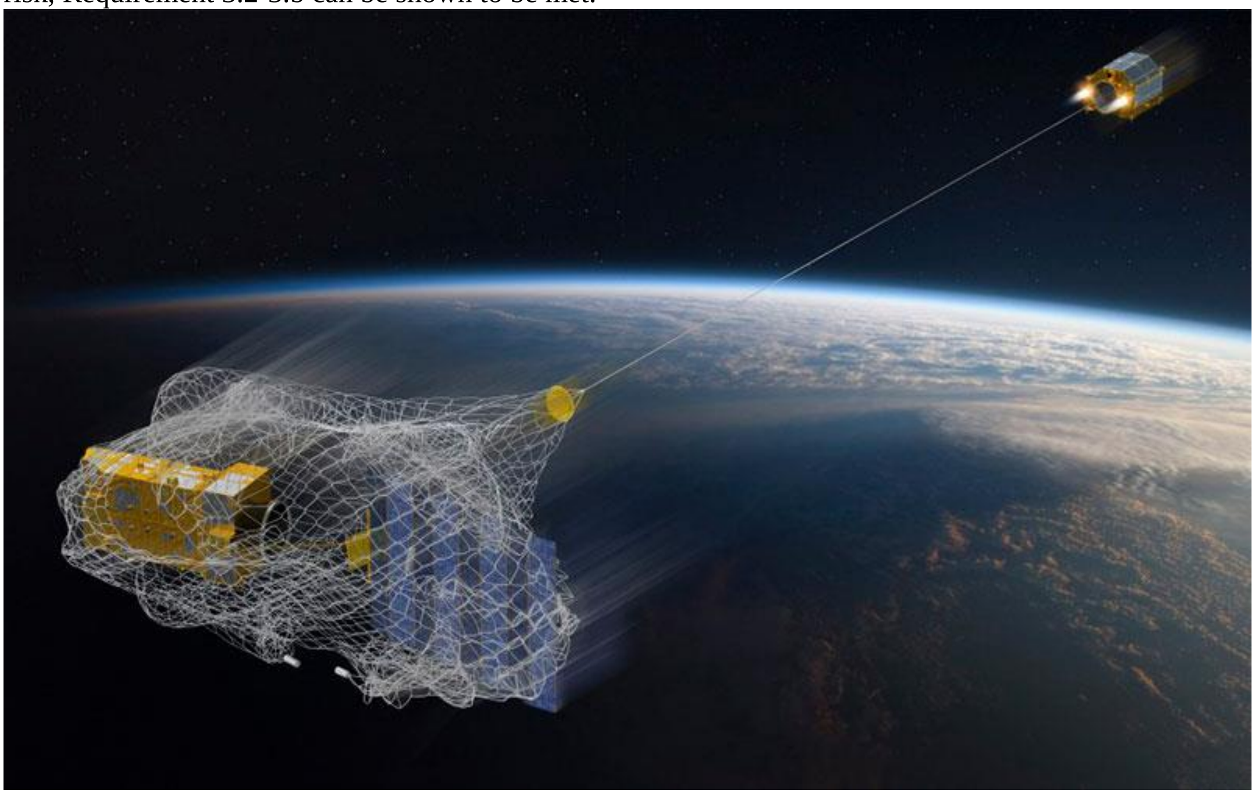

Figure 10: Concept art of the Remove Debris satellite, deployed from ISS via Kaber in June 2018

Resources

- Publicly Available Satellite Tracking Data
    - www.Space-Track.org
- CubeSat 101:
    - https://www.nasa.gov/sites/default/files/atoms/files/nasa_csli_cubesat_101_508.pdf
- NASA Debris Analysis Software and Resources
    - https://www.orbitaldebris.jsc.nasa.gov/mitigation/das.html
- NASA Technical STD. 8719.14: Process for Limiting Orbital Debris
    - https://standards.nasa.gov/documents/nasa-std-871914pdf
- JSpOC Recommendations for Optimal Cubesat Operations:
    - https://www.space-track.org/documents/Recommendations_Optimal_Cubesat_Operations_V2.pdf
- 18th Space Control Squadron CubeSat Recommendations:
    - https://swfound.org/media/205965/mckissock_cubesat_recommendations_aug2017.pdf
- Space Safety Coalition
    - https://spacesafety.org/